MIT
SEA
GRANT
PROGRAM

BEING PREPARED FOR FUTURE ARGO MERCHANTS

by

Jerome Milgram

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

Report No. MITSG 77-10
April 1977

BEING PREPARED FOR FUTURE ARGO MERCHANTS

by

Jerome Milgram

April 1977

Sea Grant Program

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

Report No. MITSG 77-10
Index No. 77-410-Nfw

Author

Jerome Milgram is an associate professor in the Massachusetts Institute of Technology Department of Ocean Engineering.

Acknowledgments

This report describes the results of research done as part of the M.I.T. Sea Grant Program with support from the Office of Sea Grant in the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, through grant number 04-6-158-44081, and from the Massachusetts Institute of Technology. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

Related Reports

Campbell, Brad, Ed Kern, Dean Horn. IMPACT OF OIL SPILLAGE FROM WORLD WAR II TANKER SINKINGS. Cambridge: Massachusetts Institute of Technology Sea Grant Program. March 1977. MITSG 77-4. $2.00.

Stolzenbach, Keith, Ole Madsen, et. al. A REVIEW AND EVALUATION OF BASIC TECHNIQUES FOR PREDICTING THE BEHAVIOR OF SURFACE OIL SLICKS. Cambridge: Massachusetts Institute of Technology Sea Grant Program. March 1977. MITSG 77-8. $5.00.

Milgram, Jerome. WAVES AND WAVE FORCES. Cambridge: Massachusetts Institute of Technology Sea Grant Program. November 1976. MITSG 76-19. 30 pp. $1.00.

Stewart, Robert J. THE INTERACTION OF WAVES AND OIL SPILLS. Cambridge: Massachusetts Institute of Technology Sea Grant Program. September 1975. MITSG 75-22. 201 pp. $4.00.

The Sea Grant Information Center maintains an inventory of each of the listed publications. The price noted with each entry includes the cost of printing, handling, and fourth class mailing. We invite orders and inquiries to:

Sea Grant Information Center
M.I.T. Sea Grant Program
Room 5-331
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

Please refer to the "MITSG" number when requesting publications.

FIGURE 1. The ARGO MERCHANT Nears her End on Fishing Rip
off Nantucket, Massachusetts
on Friday December 17, 1976

INTRODUCTION

The grounding and break-up of the ARGO MERCHANT in December, 1976 and the subsequent oil spill brought to public attention just how inadequately prepared we are for dealing with offshore oil tanker accidents. This lack of preparedness applies both to cleaning up oil from the seas as well as to salvage of the ship and cargo before or during oil spillage.

Although each marine tanker accident is different and requires a somewhat different response, there are a number of relatively common features. Therefore, by knowing the important events of the ARGO MERCHANT incident, the reader can achieve an understanding of what is needed for dealing with such events in the future. Therefore, these events are described here. Then, possible means for dealing with such events, and with similar events, in the future are described.

EVENTS OF THE ARGO MERCHANT INCIDENT RELATED TO POLLUTION OF THE SEAS

At approximately 6 a.m. on Wednesday, December 15, 1976 the ARGO MERCHANT ran aground on Fishing Rip, which is a shoal located about twenty-seven miles southeast of Nantucket Island, Massachusetts. The grounding damaged the vessel and flooding of the engine room soon began. This flooding disabled the ship's power-making machinery which resulted in power-driven machinery, such as ship's pumps, being made inoperative. Furthermore, steam could no longer be supplied to the heating coils in the ship's tanks so that the oil began to cool slowly. The ARGO MERCHANT carried No. 6 oil which is so viscous at low temperatures that it is difficult to pump. Therefore, during shipment it is usually kept warm (90° to 120°F) so that it can be pumped off the ship with relative ease when the ship arrives at its destination. Once heating steam is lost from the heating coils in the tanks, the cooling begins. This cooling takes place relatively slowly and generally it would take several days for the temperature of the oil in the ship to reach that of the surrounding sea.

At 7 a.m. on Wednesday the U.S. Coast Guard station in Woods Hole, Massachusetts received a MAYDAY message from the ship. During Wednesday, the Coast Guard delivered emergency water pumps to the ship and personnel from the Coast Guard cutters Sherman and Vigilant assisted with operating them.

During the day Wednesday, water was pumped out of the engine room by means of the pumps which the Coast Guard had brought aboard. Of course, water was leaking in at the same time because of the damage. The damage to the ship also resulted in some of the cargo of No. 6 oil leaking into the engine room. This oil was cooled off by the cold sea water and the resulting cold oil was so viscous that it fouled the pumps. The estimated sea water temperature in the engine room was about 10°C (outside in the sea the temperature was about 6°C). At 10°C the viscosity of the No. 6 oil carried by the ARGO MERCHANT was about 35,000 centipoise. To give the reader an idea of just how viscous this is, it is remarked that the viscosity of water at room temperature is about 1 centipoise and that of a typical crude oil is about 100 centipoise. The cold No. 6 oil has a consistency not very unlike that of thin

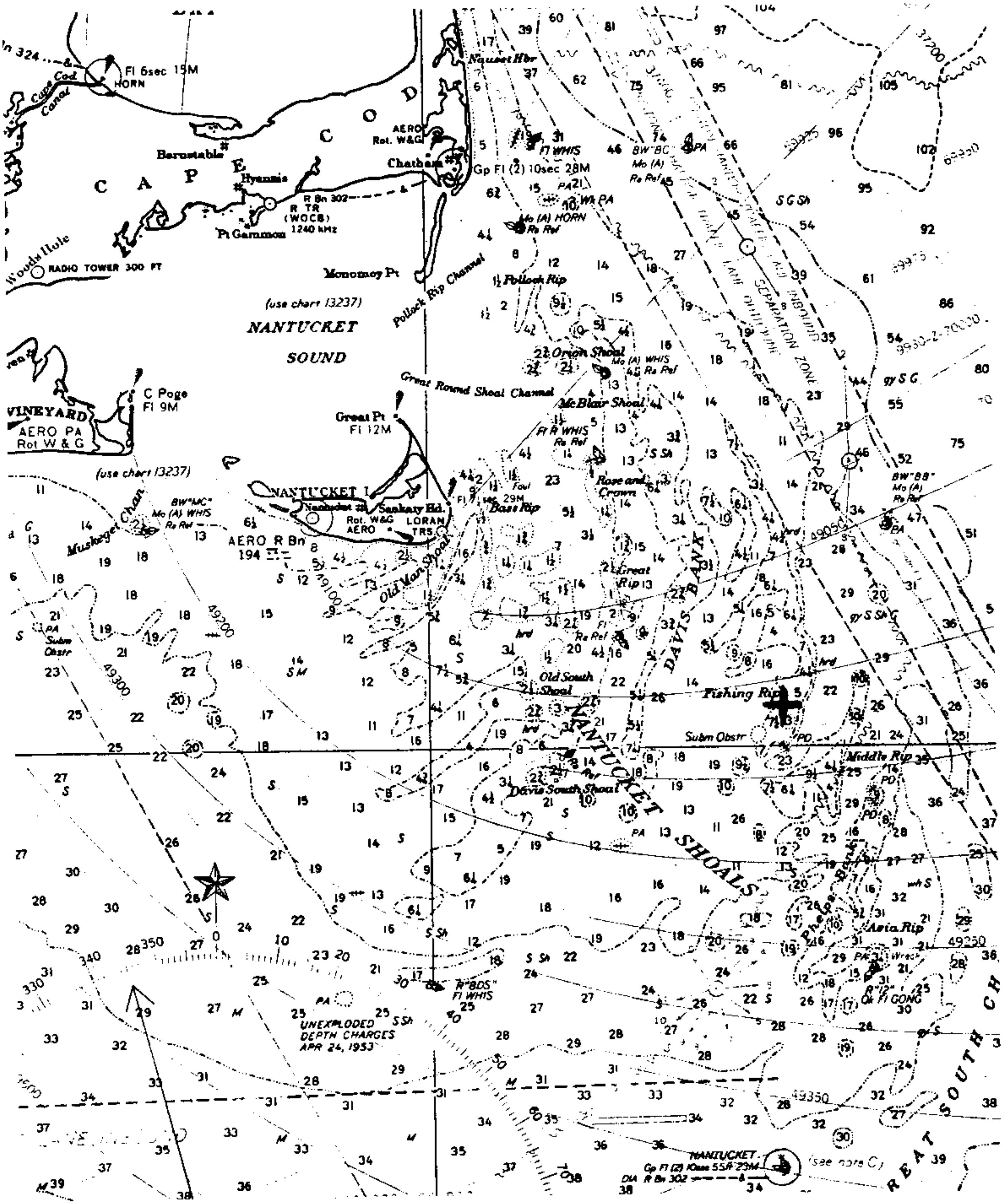

FIGURE 2. Chart of the Region Where the ARGO MERCHANT Ran Aground. The site of the grounding is marked by a +.

peanut butter.

By Wednesday evening, a Coast Guard helicopter had put strike team personnel and one ADAPTS (Air Deliverable Anti-Pollution Transfer System) pumping system aboard the vessel. Three strike teams, one on each of the Atlantic, Gulf, and Pacific coasts, are maintained by the Coast Guard for dealing with oil spills and potential oil spills. An ADAPTS pumping system is designed for offloading oil from a stricken vessel. It consists of a power source, an offloading pump, and hoses. The offloading pump is a submersible type, intended to be submerged in a ship's tank. The pump is driven by an integral hydraulic motor which operates from high pressure hydraulic fluid delivered to it through hoses by the power source. The power source is a self-contained diesel engine, hydraulic fluid pump, and associated machinery. The ADAPTS systems are designed to offload between 1,000 and 2,000 gallons of oil (having a low to moderate viscosity) per minute. In the case of the ARGO MERCHANT, the ADAPTS system was not used for offloading oil, but rather to pump water with some oil out of the flooding engine room, and into the sea. Because of moderately large winds and seas and the dark of night, more ADAPTS systems were not brought aboard during Wednesday evening. Even to get the one ADAPTS system aboard it was necessary for the Strike Force personnel to first cut loose all the ship's antenna wires that ran between the midships and after houses so that a helicopter could safely operate between the houses and lower the ADAPTS components to the ship on a cable. The ship was still the responsibility of the owners who hired the Murphy Pacific Salvage Company to carry out salvage operations, whose representative was brought aboard the ship by Coast Guard helicopter. During Wednesday evening and Thursday, while the single ADAPTS system was pumping water from the engine room, the Coast Guard personnel and the representative of Murphy Pacific studied the situation to determine the best course of action.

At this point, it is appropriate to describe some aspects of the situation in which these people found themselves. They were aboard a damaged and grounded ship with a flooding engine room, and with a heel angle sufficient for the starboard side of the main deck to be nearly awash. Furthermore, the ship had taken on an abnormal trim with the stern lower than normal and the bow higher. With the equipment and facilities that were available, it was impossible to determine the precise nature of the damage. Although the basic design parameters of the ship and even curves of ship stability were available on board, determination of the exact nature of the flooding in various parts of a ship from this information as well as heel and trim is impossible with a vessel which is simultaneously grounded and flooded. If only one of these two situations had existed, grounding or flooding, the basic loads on the vessel could be determined from measurements of the heel and trim and use of the available information. This would yield knowledge about the amount and location of flooding in the case of a damaged vessel or the magnitude and location of the load on the bottom of a grounded vessel. With the simultaneous existence of grounding and flooding, this determination could not be made. Therefore, measurements of the height of the liquid in a number of tanks were made as well as could be done under the circumstances, with the intent of comparing these with later measurements to then obtain information about the amount of flooding and its distribution. The flooding information about a stricken vessel is generally needed in order to be able to determine the best way to use whatever pumping capacity is available; in other words, to be able to decide which compartments to pump out. In the particular instance of the ARGO MERCHANT, with only a single adequate pump available and with the observed engine room flooding it was obvious that the pump should be used to empty water out of the engine room.

During Wednesday, the Coast Guard had requested that the nearest available empty barge and tug come to the scene to assist in oil offloading operations. A major problem in the rapid use of a barge for offloading a stricken tanker in the presence of large waves is that of providing fendering between the barge and stricken vessel so damage is not inflicted by waves smashing the two vessels together. The vessel owners did not have large fenders available to them and although the Coast Guard had four, three of these were hundreds of miles away. The Coast Guard made arrangements for two fenders and two more ADAPTS pumping systems to be transported to the Coast Guard Air Station on Cape Cod. The pumping systems arrived at the Air Station later on Wednesday and the fenders arrived there on Thursday.

By Thursday morning, the fifteen knot winds and six to eight foot seas that had existed in the vicinity of the ARGO MERCHANT during Wednesday had diminished. Also, the people aboard the vessel reported that the initial engine room flooding which had reached a height of twenty-two feet, had been reduced to fifteen feet by the single ADAPTS pump. By 8 a.m. on Thursday morning, the two additional ADAPTS systems were aboard the U.S. Coast Guard buoy tender BITTERSWEET in Woods Hole, Massachusetts along with additional strike team members. Shortly thereafter, the BITTERSWEET left Woods Hole for the scene of the ARGO MERCHANT.

During early Thursday afternoon, the personnel aboard the ARGO MERCHANT found that the water in the engine room was again rising. These people aboard knew that additional ADAPTS pumping systems would soon be aboard, and there must have been some question in their minds as to how they should be used. Should the additional pumps be used in the engine room to try to lower the water level there? On the other hand, some of the tanks of the vessel (the vessel contained thirty cargo tanks) appeared to be flooding. Since the vessel was heeled to starboard, should the additional ADAPTS pumps be used to pump water out of some of the apparently flooding starboard tanks in order to help right the vessel and possibly float her free of the shoal? If any tank had a large hole in its bottom, no good could be accomplished by pumping out that tank inasmuch as the tank would flood to the waterline level no matter how much water was pumped out of it. If the hole in a flooding tank were so small that water entered through the hole more slowly than water was pumped out of the tank, then the water level could be lowered and additional buoyancy thereby provided. If it could be ascertained that there were some undamaged cargo tanks, additional buoyancy could be provided to the vessel by pumping oil from such tanks overboard. Although this may have been the most appropriate thing to do if undamaged tanks could have been located, the responsibility for pumping oil overboard could not have been assumed by anybody involved, so nobody would make a decision to do this.

Here, another diversion is in order. Under circumstances that existed aboard the ARGO MERCHANT at this time, or which have and will exist on other ships under similar conditions, there is no decision an individual can take which can do him very much good. On the other hand, there are many possible decisions which can do one much personal harm. Thus, situations like this tend to inhibit decision making when effective response actually requires firm and decisive decision making. The technical matters are difficult enough. Somehow, the social and institutional pressures must be eliminated in order to encourage decision makers to take the best possible action.

The BITTERSWEET arrived alongside the ARGO MERCHANT at about 3 p.m. on Thursday. The two ADAPTS systems and additional strike force personnel were offloaded and the BITTERSWEET left the scene. Prior to this time, the responsibility for the ARGO MERCHANT was that of the owners and this was being exercised by the representative of the Murphy Pacific Salvage Company. He had decided to use one of the additional ADAPTS systems for pumping water out of one of the starboard cargo tanks which was supposed to have contained no oil when the ship left Venezuela, but which appeared to be flooding. By this time, the heel of the vessel had increased, the sinkage towards the stern was larger, and the sea state was increasing with waves beginning to break onto the deck. This resulted in considerable time being required to set up the ADAPTS system and associated hoses. The reader should try to appreciate how difficult it is for men to handle large, heavy six-inch diameter hoses covered with slippery oil on a tilted deck covered with slippery oil with waves and spray coming down upon them. It was dark by the time the pumping system had been set up on Thursday. When pumping began, it was not water which came out of the tank, but oil. This further increased the uncertainty of the situation. Could it have been that that tank was not empty when the ship began the voyage even though the crew reported that it was empty? Could a bulkhead between that tank and another tank have been damaged in the grounding, resulting in a leak so that oil from an adjacent tank poured into a previously empty tank? Could the condition of the ship before the voyage have been so bad that there was leakage between one tank and another so that an initially empty tank slowly filled up? These questions and others must have been going through people's minds and no answers to them were available.

During Thursday afternoon, the Coast Guard assumed command of the salvage operation under authority of the 1974 Federal

Intervention on the High Seas Act. No doubt this was done because the owners of the vessel had not accomplished any positive steps toward salvage. All pumping up until that time had been done by Coast Guard personnel with Coast Guard equipment. The owners had not made any plans for rapid delivery of barges, fenders, or pumps for offloading cargo, nor had they made any arrangements for cleaning up oil that had spilled or might spill later. The strike team aboard the vessel was informed of the Coast Guard intervention by radio.

At about 7 p.m. Thursday evening, a tug, the SHEILA MORAN, arrived at the scene and it appears that her assistance had been requested by the Murphy Pacific Company. Since there was nothing she could do to help at that time, she stood by on scene.

During Thursday evening, the wind strength, which was now from the northwest, increased as did the size of the waves and the amount of wave breaking onto the main deck of the vessel, whose low (starboard) side was towards the waves. Some buckling of the main deck on the aft portion of the ship had been observed, and leaking of oil from a cargo tank into the engine room around bolts or rivets in a bulkhead could be seen. In the region of this bulkhead, strange sounds were eminating from the ship structure as a result of the loads caused by the seas and the bottom against the grounded vessel. Only the one ADAPTS pump taking water out of the engine room was being used. No one aboard knew how long the ship would last. No one could know. Even though the Coast Guard had assumed command of the salvage operation, both the Coast Guard personnel and the representative of Murphy Pacific were trying to figure out the best thing to do. It was clear that at that time that there was very little that could be done immediately.

Many of the ship tanks were inspected by opening cover plates on them and a considerable number of the tanks exhibited much agitation and sloshing of the surface of the oil. This indicated that it was quite possible that the bottom of the ship was torn open in way of many tanks, in which case pumping oil out of them and overboard would most likely not have aided in ship salvage. Water was rising in the engine room and it seemed doubtful that pumping more water from the engine room with additional ADAPTS pumps would "stem the tide". Furthermore, it was deemed by everyone aboard to be extremely dangerous to work in the vicinity of the engine room because the behavior of the deck and the bulkhead between the aftermost pump room which was full of oil and the engine room, together with the sounds the structure was making, indicated that the vessel might break there at any time. As a result, a decision was reached to take the people off the vessel. This was accomplished by Coast Guard helicopters late Thursday evening. When the lights from the helicopters illuminated the scene, it became clear that a substantial rate of oil leakage into the sea had begun. It was uncertain as to how much of this oil was coming out of deck openings and how much was coming out of the damaged bottom at this time.

At about 4:30 Friday morning, the 140,000 barrel barge NEPCO 140, towed by the tug MARJORIE D. McALLISTER, finally arrived about forty-seven hours after the grounding. However, seas were about four to six feet high with worse weather predicted and the Coast Guard chose to concentrate on other tasks rather than deliver fenders to the ship and bring the barge alongside the ARGO MERCHANT. There was substantial oil pollution at this time and the author estimates the pollution rate to have been approximately 40,000 gallons per hour.

Personnel of the Coast Guard had realized the pollution threat from the beginning and had brought their high seas oil booms and skimmers to the air station at Cape Cod. Also, the Coast Guard had contracted the Murphy Pacific Company to supervise their salvage effort.

Following the grounding of the ARGO MERCHANT, the heading of the vessel changed from time to time. It is not certain how much of this heading change was due to wave forces and how much was due to forces of the currents. The currents at the location of the grounding are somewhat unique in the sense that they are rotary, not reciprocating. Whereas in most locations, tidal currents go in one direction and then switch and go in the opposite direction, on Nantucket Shoals the current direction rotates through all headings.

The salvage plans being generated by Murphy Pacific were to begin with stopping the heading changes of the ship by putting out two bow anchors. Then, plans were to locate a group of heavy moorings, each with a mooring buoy, around the ship to which barges could be tied. A work vessel was to be brought alongside the ARGO MERCHANT with fendering to be provided by the two large Coast Guard fenders which had arrived at Cape Cod. This work vessel was to contain a steam heater which could be used to pump steam through a portable coil which could be put in one ARGO MERCHANT tank after the other to heat the oil again to a temperature at which it could be pumped.

Conditions on Friday, December 17th, were somewhat rough and work was limited to inspection of the ship since all of the planned equipment for salvage was not yet available. Saturday, December 18th, was even rougher. Wind strength increased to over 40 knots and seas were nine to twelve feet high with almost every wave breaking on the shoals. Although the amount of heeling of the vessel seemed to change as the tide changed, the stern of the vessel was definitely getting lower and lower.

By Sunday morning, December 19th, the wind and seas had abated and conditions were nearly calm. In a combination of effort by Coast Guard Strike Force personnel and the tug SHEILA MORAN and her crew, one of the bow anchors of the ARGO MERCHANT was put out. In the calmer conditions, the oil leakage rate appeared to be somewhat less than before. Wind and sea conditions were also moderate on Monday, December 20th, but during the night conditions worsened. By the morning of Tuesday, December 21st, strong northwest winds and large seas were again present. At 8:30 a.m. the ARGO MERCHANT split in two and a great deal of oil escaped. By Wednesday morning, the wind strength had reached 45 knots and the seas were about twelve feet high. At about 9 a.m. on Wednesday, a section of the bow which had been afloat broke in two and most of the remaining oil escaped.

From the standpoint of pollution damage, we were all very lucky in the case of the ARGO MERCHANT accident. Although at the time of the grounding the wind was from the southwest, during all of the time that oil escaped from the vessel, all strong winds were from the north or the northwest. This resulted in the oil being driven away from the shore, but to the south of George's Bank. Following the spilling of the oil, only for one short period did the wind blow towards land and although some oil came to within fifteen miles of Nantucket Island, before it got closer the wind direction again changed to the northwest and the oil was blown out to sea.

We will not always be so lucky. Statistics about wind direction indicate that such good fortune can be expected most of the time during winter in the location of the Nantucket shore. However, most of the time does not mean all of the time.

In addition, winds toward shore are more prevalent there in the summer. There are, of course, many locations in the United States where the situation is reversed and the most frequent winds blow towards the shore.

If the ARGO MERCHANT oil had been blown onto shore, we would presently be dealing with a coastal disaster of major proportions. Any region which has a large quantity of oil blown onto its shores will have such disaster.

The preceding description of events provides a useful framework for considering optimum equipment, personnel training and planning for diminishing the magnitude of such disasters.

PREPAREDNESS FOR RESPONSE TO STRICKEN VESSELS

The technology of the salvage of vessels which are grounded offshore has shown no essential advancements during the past thirty years. A technological advance in this field can be made now if funding and the attention of competent engineers are "focused" on the problem. The subject of regulations to decrease the likelihood of tanker accidents is not a subject of this report (it is being given much attention elsewhere). However, the subject of regulations intended to make tankers easier to salvage if they run aground is indeed a subject of this report and will be considered here.

The ARGO MERCHANT lasted just slightly longer than six days after it grounded. During part of this time, the weather was quite rough. In 1970, the tanker ARROW ran aground in Chedabucto Bay, Nova Scotia. The ARROW lasted four days before breaking up. The TORREY CANYON lasted about one week.

The fact that grounded tankers generally seem to last several days after grounding indicates that the mechanism of breakup is not that of any particular instantaneous load exceeding that which the ship can initially withstand, but rather the process is one of fatigue, whereby reciprocating loads deteriorate either the macrostructure (frames, joints, etc.), the microstructure (metallurgical properties of the steel), or both over a period of several days. A feature of fatigue failure is that for specified loading conditions, a small increase in strength will often greatly extend the number of cycles a structure can withstand before ultimate failure. Since grounded tankers generally seem to last several days before breaking up, it seems quite possible that a relatively small increase in structural strength could result in grounded tankers generally lasting several weeks. Studies to determine whether this would be the case are within the capabilities of present day ship structures experts and such studies should certainly take place. If the expected lifetime of a grounded vessel could be materially increased, many salvage operations could take place which are not possible with an expected lifetime of only a few days. Therefore, if studies indicated that a modest structural strength increase would markedly increase the expected lifetime of a grounded vessel, regulations upgrading the structural standards for tankers entering U.S. waters would be appropriate.

Much has been said and written about the advisability of requiring tankers to have double bottoms to minimize the pollution threat if a tanker should run aground. In the present context, the use of double bottoms could be quite helpful for lengthening the expected longevity of grounded vessels. When a vessel runs aground, the bottom of the vessel is usually damaged. The cross-sectional shapes of large ships of today are such that the beam substantially exceeds the depth. This has been caused by the need to increase cargo holding capacity without increasing ship draft, which would limit the areas the ship could use because of limited water depth. With cross-sectional shapes which are relatively wide and shallow, the ability of the structure to withstand sidewise bending is far greater than the ability to withstand vertical bending. In vertical bending, the maximum loads are carried in the ship's bottom and the ship's deck. If the bottom is damaged upon grounding, one of the primary structural members (the bottom) for withstanding vertical bending is either less efficient or unable to contribute at all to bending restraint. On the other hand, if a vessel had a double bottom and the outer bottom were ruptured, the inner bottom could still contribute a significant amount to the provision of vertical bending restraint.

It is useful to understand the enormous amount of buoyancy which can be required to re-float a grounded vessel. The ARGO MERCHANT was a relatively small tanker by today's standards. It could carry approximately twenty seven thousand tons of oil. The weight of the ship itself, exclusive of cargo, was about 18000 tons. Suppose, for example, that the degree of damage to the ship was such that an external buoyancy equal to half of the weight of the steel of the ship had to be provided. This would be four thousand tons. One person once asked me why the ship could not have been lifted up high enough to get it off the shoal with helicopters. The helicopters having the largest lifting capacity which I know of (Sikorski Skycranes) can lift about 12 tons. Seven hundred fifty such helicopters simultaneously lifting would be required to lift the weight of half the steel of the ARGO MERCHANT. Obviously, that would not be a practical solution. There are more practical possibilities. By far, the most practical of these would be an arrangement whereby a stricken ship could float itself. It was impossible to do this with the ARGO MERCHANT with the equipment that was aboard. However, it is feasible to require that all tankers entering waters be capable of sealing all deck openings in a time of one hour or less. Retrofitting existing vessels to meet such a requirement would be entirely practical. Suppose it had been possible to completely seal all deck openings on the ARGO MERCHANT. If this could have been done, then if air were pumped into the tanks above the cargo while removing as much cargo as was displaced by the air, the four thousand tons of buoyancy could have been provided by depressing the liquid level in the ship's tanks three feet. This would have been effective if the bottom were ruptured or not. Fittings to accept air lines could be required on the top of each tank. Emergency salvage equipment could include compressors and hoses to supply the air.

Let us consider what this would have involved, had it been possible, in the case of the ARGO MERCHANT. First of all, the deck opening seals and the deck structure itself would have to have been strong enough to withstand an internal pressure of approximately two pounds per square inch above atmospheric pressure (a practical requirement). Furthermore, approximately one seventh of the ship's cargo would have to have been discharged to allow a space for the air. Under the conditions of the grounding, had this even been possible, the only practical way to discharge this cargo (which would amount to about one million gallons) would have been to discharge it overboard.

Authorizing the discharge of one million gallons of oil into the sea is a responsibility which an individual simply cannot take under existing political conditions. In the case of the ARGO MERCHANT, the impact of the oil, while severe on certain forms of life, especially sea birds, was the least possible since the oil moved offshore and apparently without damaging Georges Bank. In spite of that, all actions of the Coast Guard were mercilessly and unjustifiably attacked by the Lieutenant Governor and the Secretary for Environmental Affairs of the

Commonwealth of Massachusetts. It is not hard to imagine what the nature of these attacks would have been like if the Coast Guard officers had been in a position to save the ship and most of the cargo by discharging one million gallons. It is certain that they would have been even worse than they were in the ARGO MERCHANT case, since the public officials could link all the pollution that would then exist to direct actions of the Coast Guard.

A workable procedure for exercising human responsibility must be prearranged in a special way if optimum response to stricken tankers is to occur in the future. For each vulnerable region of the United States coastline, the most appropriate individual should be designated in advance as the one who will have the ultimate responsibility for making decisions regarding stricken vessels in his or her area. Arrangements must be made so that these individuals know in advance that they will not be held accountable for any unpleasant results resulting from well-founded decisions. For example, suppose as in the case of the ARGO MERCHANT a northwest wind would blow the oil safely offshore and that a northwest wind was forecast for at least five days. Further suppose that the deck openings could be sealed and air pumped into the tanks above the oil. The best immediate decision under these circumstances could very well be to pump one million gallons of oil overboard to re-float the ship and tow her free and to safety. Now suppose that one day after pumping one million gallons overboard the wind unexpectedly shifted and the oil were blown ashore. Under no circumstances should the person who made the decision to pump the oil overboard or the weather forecaster be held accountable for this occurrence, and this fact should be a law.

As mentioned in the beginning of this report, every oil tanker accident is different. If a grounded vessel is equipped to be able to close deck openings and withstand internal air pressure, salvage by the means described above might be appropriate in some instances. An example of such an incident is the set of conditions that surrounded the ARGO MERCHANT accident. Since the oil was No. 6 and since cargo heating had been lost, the oil could only be moved with relative ease for a few days. One day after the accident the wind began coming from the northwest with the weather forecast being for northwesterly winds of increasing strength for several days. If the tanker had been equipped to close deck openings, discharge some cargo, and fill the resulting spaces above the cargo with air, this action, with the pumping of oil overboard, would have been appropriate for the environmental conditions that existed for many days starting on Thursday morning. In other instances, such a course of action might not be appropriate. Such instances would include those where it would be more practical to offload the oil into barges and those when the prevailing wind would be certain to blow discharged oil ashore. How might a grounded tanker be salvaged under such circumstances? The first thing which would have to be known is the extent of damage. If the tanker had deck openings which could be sealed and deck structures which could stand internal pressure, much could be learned about the condition of the ship structure by measuring the pressure in each tank resulting from air being pumped into it. If there were no openings between the tank and the outside environment, and if a sudden increase in air pressure above the cargo were applied, the pressure would not subsequently slowly drop. If there was a path from the tank to the outside environment, the rise in pressure would slowly diminish after air were suddenly pumped in. Were there broken bulkheads between otherwise intact tanks in the ARGO MERCHANT? We will never know for sure. On the other hand, if the deck openings could have been sealed, and if we were prepared with the proper instruments, we could have found out. By first measuring the size of the air space above cargo and then measuring the relationship between the amount of air pumped into a tank and the resulting rise in pressure, it would be possible to determine if the internal bulkheads were intact or broken. We are a long way from being able to do this now. Not only are tankers built without the provision for complete sealing of all deck openings above tanks, but the necessary equipment for rapidly making the aforementioned measurements has not been developed. If the state of damage of a vessel were known and if some time for salvage operations could be expected to be available, the most appropriate steps could be planned and taken. It is useless to try to pump liquid cargo from a tank having a large hole to the sea. Water will enter as fast as it is pumped out. With large pumping capacity, some flotation can be provided by pumping liquid cargo from a tank having only a small hole to the sea. The best way to provide flotation by offloading cargo is to remove the cargo from intact tanks so the resulting air space will not flood, and hence be able to provide buoyancy. If this were to be done without pumping the cargo overboard, the most rapid technique would be to tie barges alongside with fenders between the barges and the stricken vessel. Doing this rapidly requires the availability not only of barges, but of lightweight rapidly deployable fendering systems. Such systems do not exist now. They could be developed.

In the case of the ARGO MERCHANT, it took about forty-seven hours for a barge to reach the scene of the incident, which was only twenty-six miles from land and 90 miles from Providence, the nearest large commercial port. Such response is too slow by at least a factor of 5. What is required for faster response by barges? The answer is that it is necessary for state or federal governments to have contracts with barge operators all around the coastline of the nation to be able to provide a prearranged amount of barge capacity on very short notice. The most appropriate contractual arrangements would appear to be those which provided barge capacity according to a certain schedule. A small amount of capacity would have to be available on very short notice. More capacity would have to be available on somewhat longer notice, and still more capacity would have to be available on still longer notice. Contracts for barge capacity on a "best effort" basis would not be sufficient. It would be necessary for barge operators to continuously demonstrate their ability to meet such contracts by means of "surprise tests" called by the contracting agency.

The individuals who would actually carry out the tasks of salvage operations would necessarily have to be highly trained. Presumably they would be groups something like the existing U.S. Coast Guard Strike Forces and quite logically could be the Strike Forces themselves. How could adequate training be assured? Again, surprise tests would have to be carried out on a frequent basis. The tests would really have to test how well the people could do. For example, at random and unannounced intervals a derelict ship filled with a non-hazardous dye could be towed up on a shoal and the strike forces called. The performance of the forces could be measured by examining how much of the dye escaped into the sea before either the ship was floated free and taken to a prearranged location or the entire cargo of dye was offloaded into barges.

One technique of marine salvage of damaged and grounded vessels is that of supplying external buoyancy to the stricken vessel by means of special flotation tanks taken to the grounded vessel which are subsequently flooded, attached to the vessel, and then pumped out to provide buoyancy. This has never been done on a scale which is appropriate for salvaging as large a ship has a modern tanker. It seems appropriate to study the possibility of developing a technology which could apply this technique on a large scale. Many changes from the smaller scale operations would be needed. For example, the only way that a flotation chamber of sufficient magnitude could be attached to a stricken vessel with sufficient strength would be to weld the chamber to the vessel. Can the technology to do this in the presence of substantial seas be developed? I certainly do not know the answer to this question now. However, we could find out by means of a relatively straightforward feasibility study.

After the grounding of a large tanker, one possibility which always seems to come to the minds of many people is that of burning the oil. Usually this cannot be done. However, it seems entirely feasible to design, develop, and construct special burners which could be placed aboard a stricken vessel for the purpose of burning the cargo. The questions which must be answered first are: How much air pollution would this cause? and how long would the burning take? Engineering studies to answer these questions are in order.

PREPAREDNESS FOR CLEANING UP SPILLED OIL OFFSHORE

Although the details of the salvage of ships and their cargoes are complicated and difficult, the fundamental technical aspects of a salvage operation are generally easily understood and relatively well-known. This is not the case for the cleanup of oil spilled on the surface of the sea which is a fundamentally more complicated subject. As a result of this, a discussion of the technical aspects of offshore oil cleanup will now be given to aid the reader in gaining a thorough understanding of the problems and the best methods of dealing with them.

First we shall consider basic geometry of an oil spill on the sea. Only rarely does an oil spill form a continuous pool of relatively constant thickness on the surface of the sea. The two factors which most strongly influence the nature of the distribution of the oil in the vicinity of the spill are the details of the way the oil is spilled and the nature of the oil spreading. Each accident has a somewhat different geometry for the spilling of oil. In some accidents, the oil is released relatively slowly and in some accidents, it is released relatively quickly. In the case of tanker groundings, the usual scenario is for a slower leak at the beginning of the process, a large release when the ship breaks up, and then a continuing slow release of oil as the broken components of the ship continue to leak the portion of the oil still aboard. It is important to point out the meaning of the word "relatively" in this context. For the ARGO MERCHANT, the best estimate by the author of the leak rate prior to breakup, but after substantial leaking had begun, is 40,000 gallons per hour. This estimate was based on direct observation of the average slick thickness, slick width, and current speed. The case of the ARGO MERCHANT demonstrates how the details of the accident can affect the nature of the geometry of the oil on the sea. As mentioned before, the tidal current direction at the location of this wreck rotates through all compass headings; the cycle being made twice each day. Although the ship changed its heading to some extent while it was grounded, this heading change was relatively small so that at different times of each day, the ship encountered currents from nearly each possible direction with respect to its own. When the current was coming from a nearly forward or aft direction, the width of the oil slick near the ship was relatively small; being approximately one hundred fifty to two hundred fifty feet. However, when the current direction was nearly athwartships, the width of the oil slick in the vicinity of the ship was between 600 and 1100 feet.

The effect of the details of oil release on the geometry of the oil are well understood and can be predicted with enough precision to determine their effect on the logistics of how to clean up the oil. This is not the case with the phenomenon of oil spreading, which is the second major effect of the geometry of oil slicks. Although some theories for the spreading of oil have been published in the literature of hydrodynamics and of oil spill effects, we are now quite certain that these theories are not applicable to spilled oil on the sea. One of the major reasons for the inapplicability of these theories is the complexity of the effects of the surface tension in the oil-air interface and the interfacial tension in the oil-water interface which are not taken into account by the theories. Generally, the effect of these tensions and the tension in the water-air interface result in a spreading force on the oil. The response of the oil to this force is extremely complicated. First of all, we must realize that most cargoes of oil are not made up of a single chemical substance, but rather are a mixture of different chemicals. This occurs to an extreme degree in the case of crude oil which is made up of a vast number of different chemical substances. Often, one or more of the chemical components of spilled oil spread more rapidly under surface tension forces than the remainder of the oil. This spreading can be very rapid and effectively contaminates a large surface area. One effect of this contamination can be to retard the spread of the remaining oil to a degree which

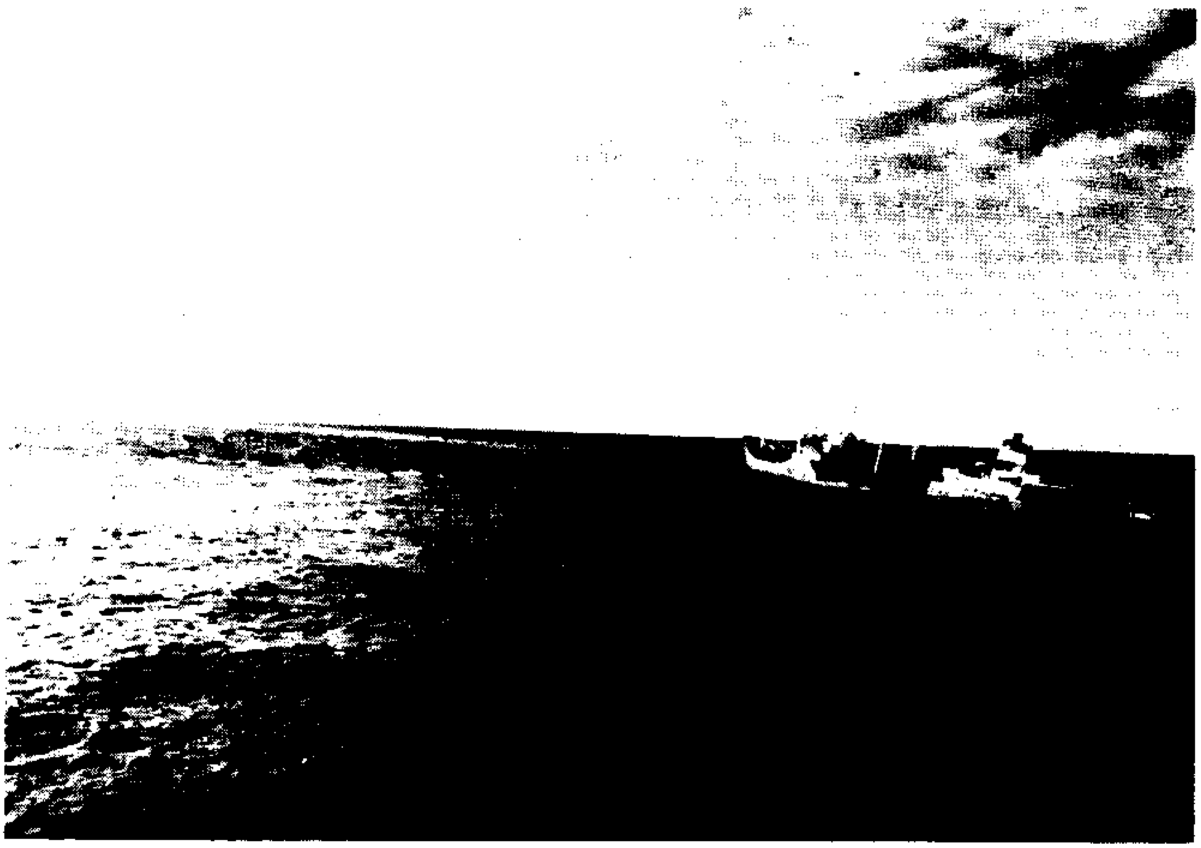

FIGURE 3. In This Photograph the Current is from the Stern Towards the Bow so the Oil Slick is only about 150 Feet Wide. It can be seen, extending to the left from the bow. When the current was athwartships, the slick was much wider.

would be unexpected if this effect were not first considered. This appears to be a contributing factor to the fact that most oil spills are found to have interspersed regions of a thin layer of oil on the surface and thick layers. The thick layers appear to float around within the thin layers and very slowly spread into the thin layers.

We can give some measures of how fast oil is expected to spread. In the event of a sudden release of a large quantity of oil, the initial stages of spreading are accurately predicted by existing published theories. This is because when the oil layer is thick (one foot thick or more) the spreading is dominated by the forces of gravity and that required to accelerate the horizontal motion of the oil in the pool; these effects being well understood. Typically, the speed of the edge of the slick in such a situation is one to two knots. However, the oil slick rapidly thins and this effect no longer dominates at distances more than a few hundred feet from the source of the leak. It is never important during a relatively slow leak. In the case of a relatively slow leak, or at distances more than a few hundred feet from a sudden oil release, the dominant surface contamination generally appears to be the surface tension spreading of the most rapidly spreading components. Typically this takes place at speeds between 0.25 knots and 1 knot. It is important to realize that under some circumstances this surface contamination can contain very little oil. These are the instances in which it is only one or two molecules in thickness (approximately 10^{-6} inch). Under some conditions, such a thin layer may be invisible. Often the thick and thin regions that people see are both much thicker than that described above, with the thick regions being 0.05 to 0.4 inches thick and the thin regions being 0.001 to 0.05 inches thick. The spreading of these later thicknesses usually takes place more slowly with spreading rates being on the order of 0.1 knot. For this condition, both the thick regions and the thin contain substantial quantities of oil.

Since a water current, either tidal, or wind or wave induced, nearly always exists at the scene of a tanker grounding, most of the oil moves with the current direction. For a relatively slow leak then, we find a track of oil moving away from the ship at about the surface current speed and with a width that is typically between 100 feet and 1500 feet wide. This general picture prevails, with the width slowly increasing, as distance from the stricken ship is increased. The increase in width occurs in two stages. The first comprises that of the most rapidly spreading components which contain extremely little oil. The second comprises the slower spreading of what most people call the thin region of the oil. These thin regions are often "fed" by spreading from the edges of the thick regions which float within the track of the slick.

In the presence of a sudden discharge of oil, we would expect a region containing discharged oil which spreads somewhat more rapidly than oil from a relatively slow discharge until the average thickness of the oil in the region diminished to approximately 1/2 inch. Typically, the more rapid spreading could be expected to exist until the general diameter of this region was between 1,000 and 4,000 feet, depending on the volume of oil that was spilled.

How do the properties of the oil itself affect the distribution of the oil in the sea? We have already discussed the importance of surface tension for oil spreading. Different cargoes have components of different surface tension. Some oils have oil-air and oil-water tensions that are so high that surface tension actually tends to contract the size of the slick. In this case, the very thin layer of one or two molecules of thickness would be absent and the remaining spreading would be related to the extent to which gravitational spreading forces can overcome viscous and surface tension retarding forces.

Another property which affects the gross spreading of the oil is the oil density. The density does not affect the relatively rapid spreading which takes place immediately after a sudden release of oil, since it affects the gravitational spreading forces and the force needed to accelerate the oil in the same way with the effects exactly counteracting each other. However, during the later stages of spreading, wherein surface tension spreading forces and gravitational spreading forces are basically counter-balanced by the interfacial friction between the oil and the water, the oil density can affect the spreading rate. In particular, the more the oil weighs, the more slowly it will spread. Nearly all oil is lighter than sea water. In fact, if it were heavier than sea water it would sink and spreading would certainly not be a consideration. To understand how increasing the weight of the oil slows down the spreading, one can think of oil that is as heavy as water. In this case, if surface tension forces were ignored, the oil would not spread at all inasmuch as the gravitational effects on this oil would be the same as if the oil were water instead.

Oil properties also affect important phenomena other than spreading. Some will be described here. When oil is spread on the sea, a small portion of it dissolves in the water and some of it evaporates into the air. From the standpoint of cleanup operations, dissolution can be considered to be unimportant since the amount that dissolves is very small, although dissolution is certainly important for considerations of oil toxicity.

The evaporation of the oil is highly dependent on oil properties. For a heavy residual oil, like that which came out of the ARGO MERCHANT, evaporation is slow and can be considered negligible over the time scale during which cleanup operations would take place. On the other hand, if gasoline were to be spilled on warm water, such as might exist during a warm sunny day in the Gulf of Mexico during the summer, nearly all of the spill could evaporate in one day. All stages of evaporation between these extremes are possible. They depend on the water temperature, the air temperature,wind, and the evaporative properties (vapor pressures) of the components of the cargo.

In addition to the reduction in amount of oil on the water by evaporation, the evaporative process is also an important contributor to what we call "weathering of the oil". This is the change in oil properties with time for oil which is on the surface of the sea. With a cargo containing a mixture of different chemicals, some will evaporate more rapidly than others so that the fractional composition of what remains changes with time.

When breaking ocean waves break on an oil covered surface, oil droplets are dispersed into the water beneath the waves. The density, viscosity, and oil-water interfacial tension have a considerable bearing on this dispersion of droplets into the water column. These properties affect how deeply the droplets will go, how many are formed, and how quickly they will rise to rejoin the slick. Typically, we expect a substantial number of droplets to be dispersed between the surface and a depth equal to about twice the wave height. Lesser quantities of droplets are dispersed at greater depth. This effect has a bearing on spill cleanup operations since surface equipment cannot encounter droplets which are dispersed to depths greater than that of the equipment.

As the reader can see, the immediate fate of spilled oil is influenced by the properties of the oil itself, the air temperature in the vicinity of the spill, and the sea and current conditions that exist in the spill vicinity. Clearly there are many advantages to optimum rapid cleanup response as this minimizes the extent to which the oil spreads or has been carried by waves and currents. The more the oil spreads and the greater the distance to which it has been carried, the more difficult it is to clean up. One element of being able to generate the optimum logistical plans for cleaning up the spill rapidly is that of knowing the oil properties as well as weather and sea conditions. The appropriateness of requiring prearranged plans to have this information available for every tanker entering U.S. waters should be studied at once.

There are a number of hydrodynamic limitations on oil spill cleanup operations which must be considered. Any device which collects oil moves at some speed with respect to the oil and water. If the oil and water are essentially stationary, the device must move in order to encounter a continuing stream of oil. If the oil and water are moving in a current, the device can either move at some speed or be stationary in order to encounter oil. In either case, there is a relative speed between the liquids and the device. To some extent, any device slows down the speed of at least some of the encountered oil. Considerable research has taken place on the hydrodynamic effects that occur when oil is slowed down in a relative current. For purposes of illustration, we consider here slowing down oil by a simple oil boom. This is just a floating fence as shown in Figure 4. In the presence of a relative current of low speed, the oil is held against

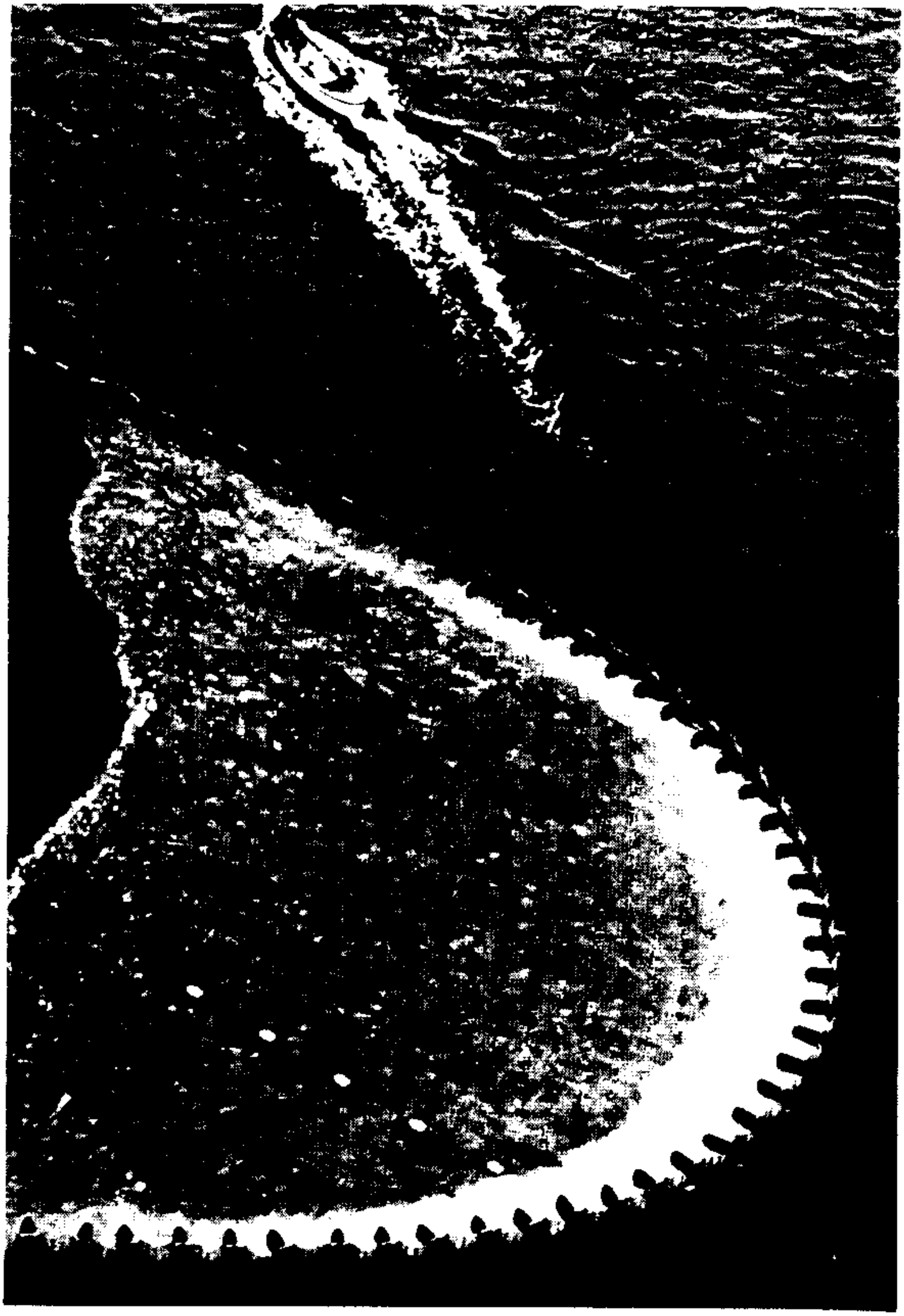

FIGURE 4. Aerial Photograph of an Oil Boom Holding Oil. The boom is being towed by two tow vessels off the picture to the left. The tow speed through the water is about 1 knot.

the boom as shown in Figure 5. For very low current speeds (less than 0.5 knot) and in the absence of ocean waves, the cross-sectional shape of the oil pool, as viewed from the side, is relatively smooth as sketched in the figure. At a higher speed of about 0.75 knot, the cross-sectional shape of the oil pool forms a lump near its leading edge, as shown in the figure. At a still higher speed of about 1 knot, the size of this leading edge lump, called a headwave, is increased. At an even higher speed (about 1.25 knots), oil droplets are torn off the headwave by the water stream and these droplets are carried below and past the boom or collection device. This particular effect has nothing to do with any details of any device except for the fact that some of the oil is slowed down. The effect results in a natural limitation in the relative speed of any containment or cleanup device of about one knot. Exceeding this limit will result in entrainment of oil in the water with this entrained oil moving under and past the device.

Some development has taken place on cleanup devices that slow down both the water and the oil to an extent that allows some cleanup at relative speeds up to two knots. However, the nature of these devices limits them to low collection rates so that they are not appropriate for large spills on the high seas. Thus, the one knot limit for high seas cleanup of large spills remains.

The limitation in relative speed of one knot affects two areas of oil cleanup operation. The first is that of properly manipulating cleanup devices. Only under relatively rare circumstances can cleanup devices operate efficiently when anchored. These circumstances would be those when the water speed is large enough to carry a substantial amount of oil to the device but still less than one knot. Usually, in the

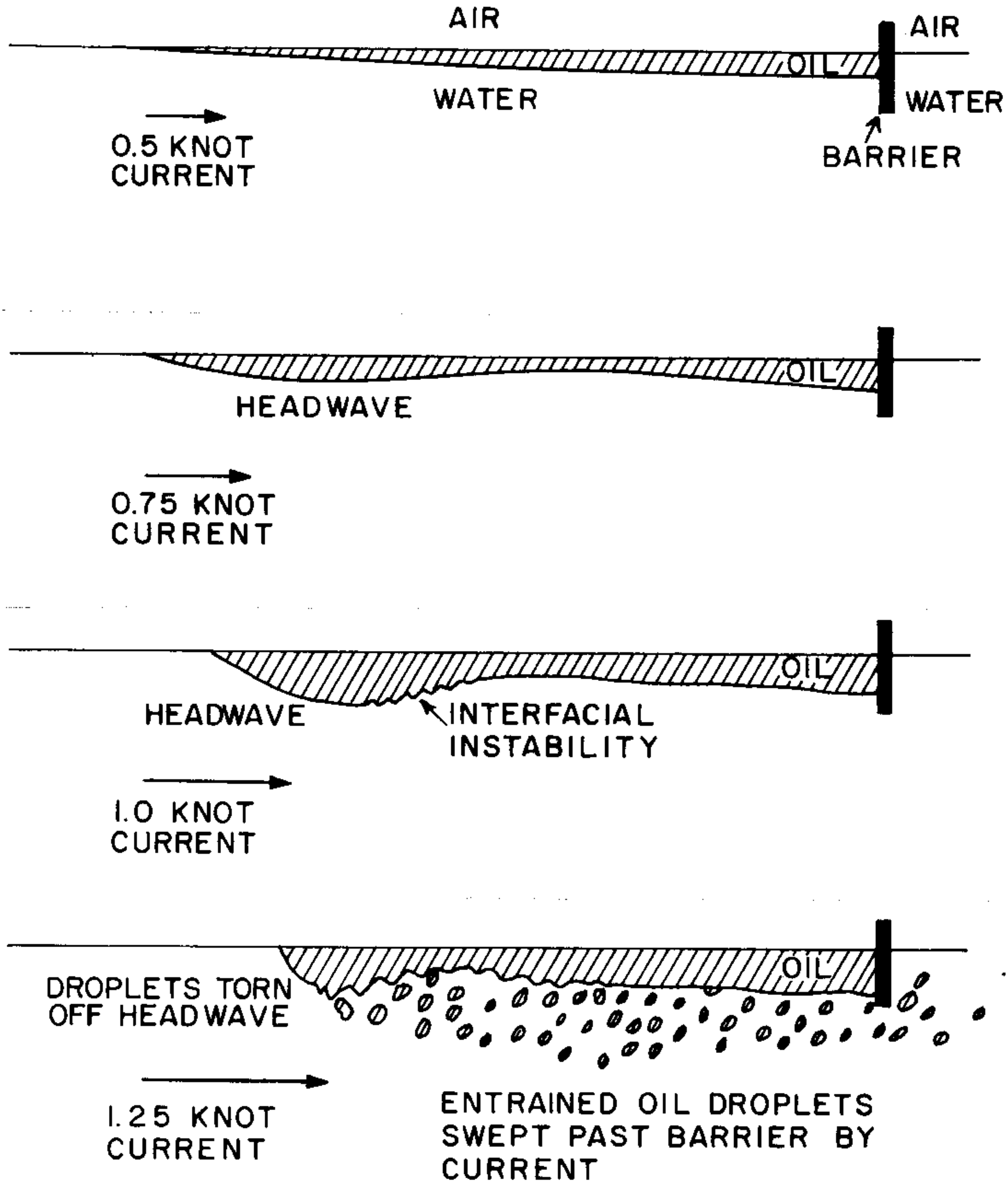

FIGURE 5. Sketches of Side Views of Oil Held by a Barrier Against a Current. As the current speed increases a headwave forms which becomes so unstable at speeds in excess of 1 knot, that oil droplets are torn off it and these droplets are entrained in the water and swept past the barrier.

presence of currents of varying strength and direction, effective oil spill cleanup requires the towing and maneuvering of cleanup devices. Such towing and maneuvering must be done at a relative current speed of 1 knot or less to avoid entrainment of oil in the water column. This limits the types of vessels which can be used to those which can go this slowly and still maintain accurate steering control in the presence of substantial waves. Most vessels have good control at higher speeds, but only very few can maintain sufficient steering control to properly tow and maneuver cleanup equipment at speeds of one knot or less.

The second area affected is that of oil encounter rate. The first phases of the ARGO MERCHANT incident provide a good example of typical leak rates in an oil tanker grounding. The estimated leak rate of 40,000 gallons per hour corresponds to 667 gallons per minute. The width of the portion of this slick containing substantial oil in the vicinity of the ship was observed to be between 150 and 1100 feet, depending mainly on the current direction. A typical current velocity was about 1.5 knots in the general area (although it was often larger over localized areas). This current speed, along with the aforementioned leak rates and range of slick widths, corresponds to a range of average slick thicknesses from 0.0070 in. to 0.046 in. (0.18 millimeters to 1.18 millimeters). These relatively small mean thicknesses, which are typical, together with the one knot limitation on encounter speed, limit the oil encounter rate of the containment or collection device. For example, for the mean of the two thicknesses given which is 0.026 inches (0.67 millimeters) the encounter rate of a skimming vessel moving at a relative speed of one knot with a skimming width of 75 feet would be 124 gallons per minute. This is only about 19% of the leakage rate in the example and is a very small collection rate for a large skimming device. For the case where the current was crosswise to the ship leading to a slick width of about 1100 feet, the oil encounter rate (which would be the maximum possible collection rate) of a seventy five foot wide skimming vessel would be only 34 gallons per minute.

The only practical device for encountering a high rate of oil flow which could lead to a high collection rate is a barrier. High seas oil pollution control barriers are made of flexible material and are strong enough to be used in lengths up to thousands of feet. As a result, a towed barrier forms a device for being able to encounter a large oil flow rate. For the example cited above, all of the oil (667 gallons per minute) could be encountered by a barrier. By utilizing a skimming device within the barrier as shown in Figure 6, or skimmers built into the barrier as shown in Figure 7, large collection rates could be achieved.

For the example given above, the current speed was 1.5 knots, whereas it has been stated that the relative speed of collection equipment cannot exceed one knot. This means that even with a barrier based collection system, one system could not handle all of the job. The reason for this is that at a relative speed of one knot, the system would essentially back away from the wreck at an absolute speed over the bottom of one half knot. This means that as the distance of the collection system from the wreck increased, it would be necessary for a second collection system to start near the wreck and slowly back away. The problem of determining the number of cleanup systems and their paths whereby they return without oil to the scene of a wreck after they reach a certain distance away from the wreck is a problem in pre-planned oil spill logistics whose solution could be worked out.

Another hydrodynamic limitation on oil spill cleanup is

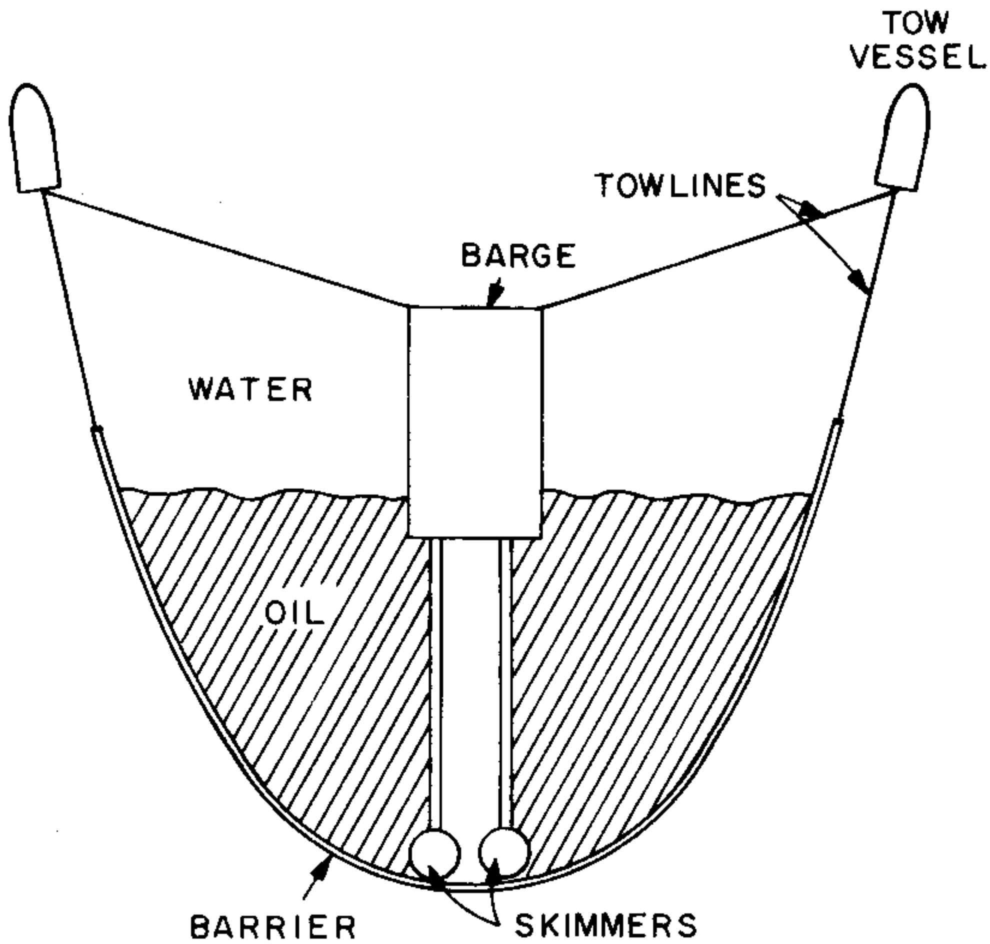

FIGURE 6. Top View Sketch of an Arrangement for High Volume Collection of Spilled Oil Offshore with Skimmers Inside U-Configuration of Towed Barrier. The barrier provides high oil encounter rate and a thick pool of oil in which the skimmers can operate efficiently. The tow vessels must not tow faster than 1 knot through the water. The oil shown in the sketch is the thick pool. Generally a thin pool is encountered ahead of the tow vessels.

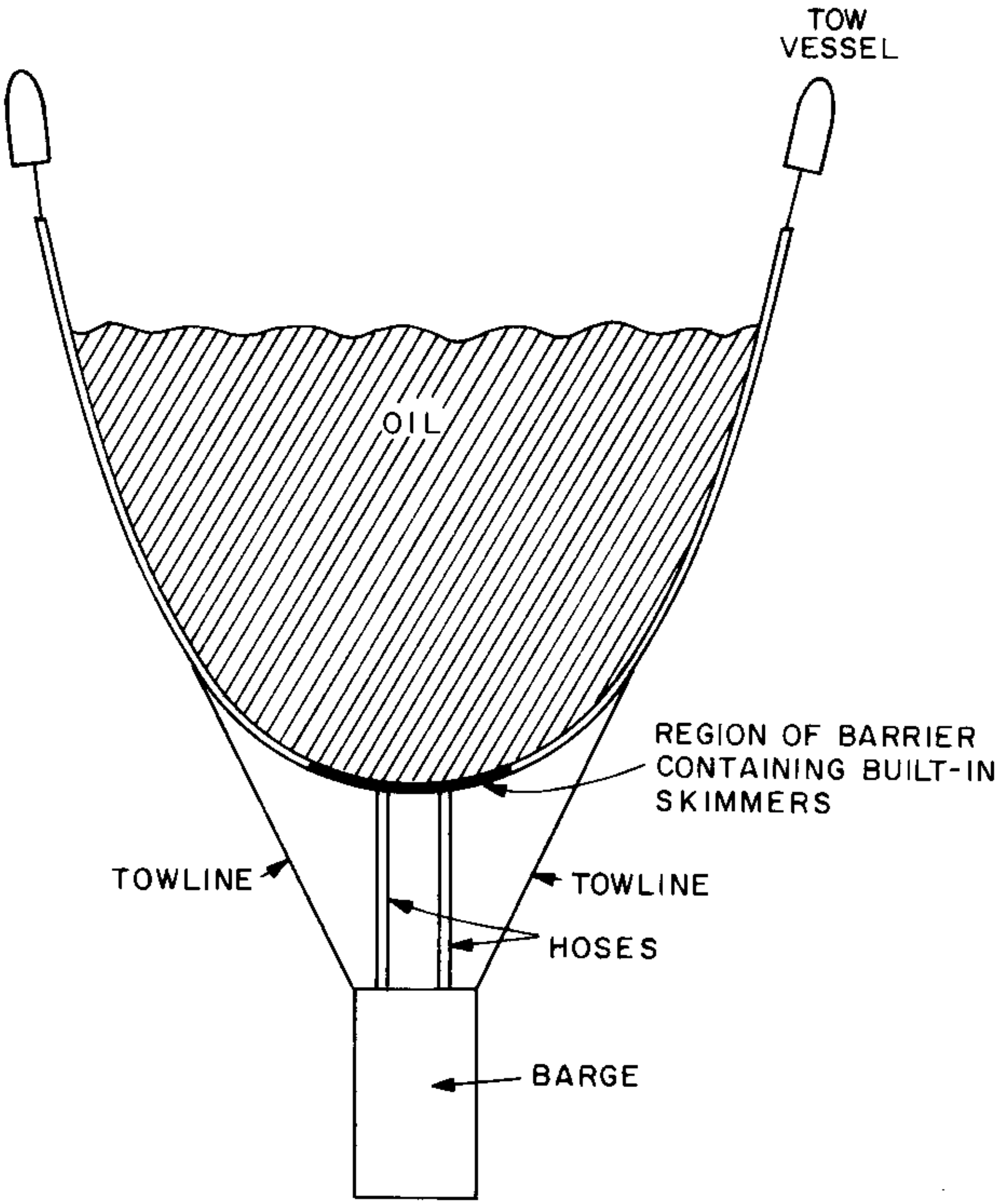

FIGURE 7. Top View Sketch of High Volume Collection of Spilled Oil Offshore Using a Barrier with Built-In Skimmers.

that imposed by the motion of ocean waves. Most cleanup systems can collect a large volume of oil and only a small volume of water only if they follow the motion of the waves on the surface of the sea relatively well. Such wave following motion is nearly impossible at the bow of a collection vessel. Under a great number of circumstances, the relative motion, up and down, of the fluid at the bow can be expected to be the same order of magnitude as the wave height. Thus, in a wave that is six feet high, there are many circumstances where the waterline at the bow of a collection vessel would move up and down by six feet. Under these circumstances, efficient collection of oil would be essentially impossible. Some work has been done leading to devices having articulated oil inlet devices at the bow of a vessel so as to adjust, in part, for the relative motion between the fluid and the vessel. This leads to a partial solution for very small waves (three feet or less), but another limitation may make refinement of this technique useless. This is the fact that when a vessel has a large relative motion with respect to the fluid, such as is the case with the vertical motion at the bow of a cleanup vessel, the motion of the vessel generates waves which drive much of the oil away, thereby making effective cleanup impossible.

The oil containment and cleanup devices which have the very best wave following ability can be divided into two categories. The first is that of specially designed high seas barriers which can have skimmers built into them. These barriers are designed to carry much of the sealoads in lines external to the barrier sheets (fabric fences), thereby leaving the barrier sheet relatively free to respond to the motion of the water and oil. The second category is that of skimmers in which the skimming device is relatively small and relatively light. Small and light devices with relatively large water plane areas can follow the surface of the sea to much greater accuracy than large cumbersome devices. A multiplicity of small devices can do a much better job in this regard than a single large device. To provide high collection rates with floating skimmers, they must be used inside a barrier.

Even though barrier based skimming systems appear to be the only feasible way to collect large quantities of oil from the open sea, their use is limited by the size of the waves. No barrier systems yet designed can work effectively in large breaking waves. Tests indicate that the maximum breaking wave height in which barriers now available can contain and collect oil, is about 8 feet. Much larger non-breaking waves (swell) can be accommodated. Larger barriers that could effectively work in larger seas could certainly be designed and constructed, but their size and weight would probably make them impractical for use.

It is useful to speculate on how effective oil barriers could have been in containing or controlling oil from the ARGO MERCHANT if they had been used. If appropriate vessels for towing and maneuvering barriers had been available, the limiting factor on barrier effectiveness would have been the sea state. Table I lists sea conditions in the vicinity of Fishing Rip for the period of December 15 to December 31, 1976. The table gives the best estimate of the author (who has participated in many tests of barriers offshore; two being with oil) of how effective the U.S. Coast Guard high seas barriers could have been on each day. Reference to the table shows that totally effective or effective operation of barriers could have been possible on 10 out of 17 days. However, it is important to note that barriers would not have been effective on the days the ship broke up, releasing most of the

TABLE I

Sea Conditions and Estimate of How Effective
U.S. Coast Guard High Seas Barriers Could Have Been

DATE	SEA CONDITION	POTENTIAL EFFECTIVENESS OF BARRIERS	COMMENTS
Dec. 15	rough, 10 ft. waves	ineffective	only small leak
16	calm, 1 ft. waves	totally effective	larger oil leak
17	medium, 4 ft. waves	effective	substantial oil leak
18	rough, 6-9 ft. waves	ineffective	substantial oil leak
19	calm, very small waves	totally effective	substantial oil leak
20	calm, small waves	totally effective	approximate total oil spilled = 2 million gallons
21	rough, 7-9 ft. waves	ineffective	ship broke up, releasing much oil
22	rough, 10 ft. waves	ineffective	bow section broke, releasing much oil
23	calm, 3 ft. swells	totally effective	
24	medium, 4 ft. waves	effective	
25	medium, 5 ft. waves	effective	
26	medium, 3 ft. waves	effective	
27	rough, 8-9 ft. waves	ineffective	
28	medium	effective	
29	rough, 4 ft. breaking waves plus 6 ft. swells	partially effective	
30	rough, 7 ft. breaking waves plus 14 ft. swells	ineffective	
31	medium, 2 ft. waves plus 6 ft. swells	effective	

KEY

Totally Effective - Barrier could hold and collect oil with negligible oil loss under or over barrier.
Effective - Barrier could hold and collect oil with small oil loss past barrier on the order of 5 gallons per minute.
Partially Effective - Barrier could hold and collect oil, but oil loss past barrier would be on the order of 40 gallons per minute.
Ineffective - Oil loss past barrier would be on the order of 150 gallons per minute or more if there were a pool of oil inside the barrier.

oil. This highlights the need for being able to collect thin layers of oil after considerable spreading has taken place.

Barriers were not used in the case of the ARGO MERCHANT accident for several reasons. Notable among them is the fact that tow vessels which can maneuver barriers at speeds of one knot or less while maintaining steering control in big waves are very few in number and simply were not available. Furthermore, the question arises as to what one would do with cold No. 6 oil contained in a barrier. It is too viscous to pump by any ordinary methods. Given that condition and the fact that the prevailing currents were carrying the oil out to sea, use of barriers without collection was inadvisable. However, if prevailing currents had been carrying the oil towards land, and had barrier towing and maneuvering vessels been available, it would then have been advisable to use the barriers to contain much of the oil and tow it out to sea with the hope that the wind direction would change before oil which was deposited far out at sea would be blown back on land.

Now we are in a position to consider what is necessary to achieve a state of preparedness which is adequate to collect large quantities of oil from offshore spills and to provide significant protection to land areas from oil which is so viscous that it is not practical to pump it. First, we must consider the means of transportation of equipment and people to the scene of an oil spill. Since maneuvering vessels are going to be needed in any case, waterborne transportation is the method of choice. It should be noted that this is different from some aspects of tanker salvage operations wherein optimum transportation of people and at least lightweight equipment is by helicopter. Waterborne transportation can be expected to have a speed of about 14 knots in moderate weather. The number of locations at which equipment and recovery vessels must be stockpiled depends on the distance from shore that we wish to be able to work at, as well as the response time. It is sufficient to discuss these matters in approximate terms. Roughly speaking, a response time of five hours for distances up to 25 miles offshore would seem acceptable. This would certainly be much better than we can do now. To protect a stretch of coastline under such conditions would require stations of equipment to be located approximately 130 miles apart. In consideration of the fact that it is impractical to protect the entire United States coastline to this extent, the approximate number of stockpiling stations would have to be about 20. If Great Lakes protection were also to be provided as well, about thirty stockpiling locations would be needed. The items needed at each station shortly upon notification of a spill are barriers with built-in skimmers or separate skimmers, storage vessels, tow vessels, and trained personnel. Each of these will be described in turn.

Barriers are the most highly developed of all of the required items for a complete spill cleanup system. Barriers capable of working on the high seas in breaking waves up to 8 feet high and in very large non-breaking waves exist, although in inadequate numbers. Some of these barriers are available in lengths of about 600 feet packaged in containers with the total loaded package weight of about 15,000 pounds. The United States Coast Guard has developed special sleds on which the packages of barrier can be towed at speeds up to 20 knots. These sleds are expected to be available in the very near future so that the problem of an adequate supply and ability to transport barriers are only those of stockpiling and routine maintenance.

The next element needed for a high seas oil cleanup system is the provision of skimmers that can work effectively together with barriers. At least three different skimmer types have been developed for high seas use. One is designed to be built directly into a high seas barrier so that once a barrier is deployed, the skimmer is automatically also deployed. None of the skimmer types is appropriate for use in a large spill of cold No. 6 oil because of the difficulty of pumping this material, but most oil transported is not No. 6 oil and initially it would seem advisable to forego the possibility of collecting No. 6. None of the seemingly useful types which have been developed for large offshore spills have been thoroughly tested offshore with large quantities of oil. Each has been tested in testing tanks. It is the author's opinion that offshore tests of the most appropriate skimmer types with oil are an absolute necessity so that confirmation of their capabilities will be available in order to aid in planning for cleaning up oil spills.

Packaged barriers and skimmers can be carried to the scene of a spill on high speed planing sleds towed by high speed vessels. For example, the barriers and skimmers whose use is presently being contemplated by the U.S. Coast Guard can all be towed at speeds in excess of fourteen knots by the Coast Guard 82-foot cutters as well as some of the larger Coast Guard vessels. The packaged barriers are especially designed for rapid deployment (it takes about 20 minutes to deploy a 600-foot long barrier from a container and barriers can be connected together to give a longer barrier), so that rapid availability of skimmers and barriers is possible. Rapid availability of collection vessels which can be used to store collected oil does not exist. Several attempts have been made to develop large lightweight rubber bags suitable for this purpose, but tests of these bags have resulted in their structural failure. One element which must be developed in order to fulfill the needs of a total spill cleanup system is that of storage capability. A consideration of this subject indicates that two different types of storage capability are needed. The first is that of special newly designed small barges. These would be vessels having an overall length of about 75 feet, which would be stored near stockpiles of barriers and skimmers. These vessels would be designed as lightly as possible in order that they could be towed by the same type of vessels that could be used to tow sleds containing boxes of barriers and skimmers. In effect, the capacity of such a collection barge would be that of the largest barge, which vessels such as Coast Guard 82-foot cutters could tow at speeds of 14 knots or more when empty. Preliminary calculations indicate that vessels of this type could have a storage capacity of about 100,000 gallons of oil which would represent about three hours of oil collection from the barrier skimmer combination that was collecting oil at a rate of approximately 600 gallons per minute. These storage barges should also be designed to achieve gravity separation of oil and water since some water is collected with all skimmers and separation would allow discharge of the water so more oil could be collected.

The second aspect of the storage system is that of the availability of commercial barges. Some organization or agency must take the responsibility for generating contracts with a great many barge operators around the coasts of the United States. These contracts must be arranged so that empty barge capacity is available on a few hours notice. The required capacity could be on a scheduled basis where an initial capacity in each location is provided within a relatively short time (for example, 8 hours) and more capacity is provided over a longer time. By this means, the immediate storage capacity response to an oil spill could be provided by the special small barges which could be towed at high speed, with arrangements made for these barges to be able to offload collected oil into the commercial barges at a later time.

The next needed item for a total spill cleanup system is that of maneuvering vessels. As has been explained previously, it will generally be impractical to moor oil spill cleanup systems in the vicinity of a tanker grounding. Effective cleanup requires towing of barrier-skimmer combinations at a speed of one knot or less. Figure 7 is a sketch of what the author believes will be the most effective total spill cleanup system. Vessels which are capable of towing at speeds of one knot or less and still maintaining steerage control in waves of substantial size are few in number. The power requirements for this towing are particularly small; a few hundred horse-power is more than sufficient. The two problems that do exist are the ability to tow continuously at a slow enough speed and the ability to have adequate steering control to properly handle barrier-skimmer combinations at such low speeds. It is quite within our capabilities to retrofit a large number of existing vessels to provide them with this added capability. To date, hardly any such retrofitting has been done. Since several barrier-skimmer-barge combinations can be expected to be needed at the scene of an offshore oil spill, numerous tow vessels must be available at each location. It would be entirely feasible to add the low speed towing capability to the same vessels which were to be used for high speed response with equipment and personnel.

This brings us to the matter of trained personnel. Cleanup of an oil spill offshore is a difficult task and requires personnel who are thoroughly trained in the job that they are to do. Just as is the case with training and practice for salvaging stricken vessels and their cargoes, training and practice of cleanup personnel are needed as well. Because of the availability of air transportation for people, trained personnel need not be stationed at every location where equipment is stockpiled. The present U.S. Coast Guard Strike Force concept could be used if the number of strike forces were increased in number and if thorough and regular training took place.

This completes the description of what is needed for a total spill cleanup system; barriers, skimmers, storage vessels, tow vessels, and trained personnel. If any one of these elements is absent, essentially no oil cleanup can take place even if all of the remaining items are provided.